DOCUMENT RESUME

ED 368 576 SE 054 339

AUTHOR van den Berg, Euwe; And Others
TITLE The Role of "Experiments" in Conceptual Change: A Teaching-Experiment Study of Electric Circuits.
PUB DATE Mar 94
NOTE 21p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Anaheim, CA, March 26-29, 1994).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Concept Formation; Educational Research; *Electric Circuits; Foreign Countries; High Schools; *Physics; *Science Experiments; *Science Instruction; Science Teachers; Scientific Concepts
IDENTIFIERS *Hands on Science; Indonesia (Java)

ABSTRACT

This paper addresses the role experiments can play in concept development. The study used a qualitative phenomenography research methodology. The interactions of one student with an instructor in a series of eight sessions on electric circuits is reported. The first three session focused on diagnosing the students' prior conceptions of electric circuits. The remaining five sessions focused on teaching interventions designed to help the student develop more knowledge about circuits. Among the conclusions was that the hands-on science activities were effective in facilitating learning of correct relationships in circuits. However, the practical activities alone did not enable the subject to develop a fully scientific model of a circuit system. (Contains 50 references.) (PR)

THE ROLE OF "EXPERIMENTS" IN CONCEPTUAL CHANGE:

A Teaching - Experiment Study of Electric circuits

Euwe van den Berg

Vrije Universiteit

Amsterdam, The Netherlands

Nggandi Katu

Universitas Kristen Satya Wacana

Salatiga, Indonesia

Vincent N. Lunetta

The Pennsylvania State University

University Park, PA, USA

March 24, 1994

Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Anaheim, March 26-29, 1994.

Introduction

Experiments play an important role in the rhetoric of scientists and science educators. The promotion of "activity" or "laboratory" based science continues around the world even though many studies have placed careful question marks behind the presumed outcomes of laboratory instruction (Bates, 1978; Hofstein & Lunetta, 1982; Garrett & Roberts, 1982; Hodson, 1990, 1993). Experiments in science instruction are used for a variety of different purposes (Shulman & Tamir, 1973): a) to arouse and maintain interest and curiosity in science, b) to develop creative thinking and problem-solving ability, c) to promote aspects of scientific thinking and the scientific method and process skills, d) to develop conceptual understanding and ability, and e) to develop skills in experimental techniques (Berg & Giddings, 1992). This paper concerns the role of experiments in developing conceptual understanding.

In a review of research on the use of student laboratory experiments Bates (1978, p74) stated: "Lecture, demonstration and laboratory teaching methods appear equally effective in transmitting science content". Hofstein and Lunetta (1982) and Garrett and Roberts (1982) in independent reviews reached a similar conclusion. Van den Berg and Giddings (1992) pointed to some possible causes: the choice of student laboratory experiments frequently is based more on tradition than pedagogy; preconceptions are not considered, and frequently there are mismatches between laboratory goals on the one hand, and worksheets, teacher guidance, and assessment on the other hand. Early in the movement to study alternative conceptions Nussbaum and Novick (1982) offered interesting advice with regard to experiments to support conceptual development. They described a conceptual conflict strategy which provides guidelines for a choice of experiments and other instructional strategies. Among other things, they recommended strategies that would have counterintuitive outcomes such as predict-observe-explain demonstrations (White & Gunstone, 1992). Cognitive conflict experiments do not (and perhaps cannot) lead automatically to conceptual change. Their role is to raise questions, to confront students with the limited validity of their current (pre)conceptions and motivate them to think about their conceptions. Furthermore, cognitive conflict potentially could create powerful episodes (White, 1979) which could help trigger the red warning lights in situations where intuitive conceptions are invalid (we assume that intuitive conceptions remain dormant rather than disappear and that cognitive addition of old and new conceptions rather than transformation or reconstruction of preconceptions). It should be pointed out that in real classrooms cognitive conflict experiments frequently do not cause cognitive conflict in students due to insufficient teacher imposed structure and control of the teacher, improperly focussed attention of students, and/or lack of involvement. In this connection we also refer to Atkinson (1990) who reported on the frequently irrelevant memories of students about experiments. Cognitive conflict needs to be followed up by other methods such as anchoring and bridging analogies (Clement et al, 1989; Clement, 1994) to achieve conceptual change. Also in this conflict-resolving phase, experiments can play a role, for example in visualizing an analogy or developing a model. In short, it is important to specify a) what role experiments can play in concept development, b) when experiments can help, and c) how experiments should be embedded and used in lessons. This paper concerns aspects of question a), that is what role experiments can play in concept development.

Pedagogically experiments can play one of the following roles in concept development (the list is not exhaustive):

a) showing/exploring phenomena, for example, at the start of a new topic an experiment can elicit ideas and questions of students, and the following discussion can help in developing some language necessary for a new topic.

b) verification experiments in which book knowledge is verified (implanting the idea that theories should match experience with "the world" is important);

c) predict-observe-explain (cognitive conflict) experiments or demonstrations which aim at making students aware of their conceptions (prediction phase) and the possible lack of validity of these conceptions (observe) and which then motivates them to reflect (explain) and study (White & Gunstone, 1992);

d) anchor-bridges experiments in which a teacher starts with an experimental situation where students intuitively tend to make the proper predictions (anchor situation) and where via various conceptual bridging experiments the implications of the anchor situation are generalized to situations where students would tend to make unscientific predictions (Minstrell, 1982; Clement, 1994);

e) enhancement of detail or articulation experiments that aim to explore phenomena in more detail and in which often a need arises to introduce new variables or sharpen definitions of already known variables, for example, the need to introduce the concept of acceleration and to contrast that with velocity in kinematics experiments (Dekkers & Thijs, 1993);

f) visualization/simulation/modelling experiments, for example, using some balls and a lamp to sir :late the appearance of the moon or the seasons on earth, or use of some common objects to visualize the situation of a physics problem to be solved;

g) hypothesis testing where students are involved in formulating an hypothesis, and the procedures to test it, and then carry out or observe the experiment;

h) linking book science to everyday-life contexts.

Recently Chinn and Brewer (1993) studied the reactions of children and scientists to anomalous data. They defined 7 different ways of dealing with anomalous data, only one of which would result in major knowledge restructuring (accommodation). Some of the other ways were: methodological error (rejection of the data because of experimental error), random error (data just happen to come out a certain way), fraud (data are thought to have been doctored), declaring the data to be outside the domain of the theory and then ignoring them (those data concern chemistry, not physics). It would be interesting to explore these ideas in more depth with students.

Alternative conceptions regarding voltage, current, and circuits have been studied extensively (Fredette & Lochhead, 1980; Osborne, 1982; Cohen et al., 1983; Shipstone, 1984; Duit et al., 1985; Dupin & Johsua, 1987; Cosgrove et al., 1985; Psillos et al., 1988; McDermott & Shaffer, 1992). We refer to the bibliography of Duit & Pfundt (1991) for a rather complete listing. Cross-cultural studies have shown a remarkable universality (Shipstone et al., 1988; Berg et al., 1992; Thijs & Berg, 1993). Many remediation studies have been conducted using rather different approaches. In the approach of Steinberg and Brown (1993) capacitors play a major role. Niedderer and Goldberg (1993) have used computer programs and a wind analogy. Licht (1990) used the idea of charge density to visualize electric potential and voltage. Licht's approach is applicable to most simple circuits (without capacitors. Five years later teachers have continued use of the idea and the computer program which accompanied it. Dupin and Joshua (1989) have experimented with various analogies. The well known water analogy turned out not to work to well as students do not know enough about water flows to benefit from it. Niedderer (1992) also reports disappointments with the water analogy.

The topic of electric circuits lends itself eminently to the study of the role of experiments in learning. Experiments are immediate and accurate. There is no need to disregard factors like friction. Equipment is simple and not mysterious. In an interview study like the following, electric circuit experiments can be instantly adapted to whatever direction the interview takes.

Although some science educators have claimed success in promoting changes and

development of more scientific conceptions (including the area of electric circuits), others have expressed concerns about: (1) the extent to which their instructional strategies influence the status of individual students' thinking; (2) their knowledge of individual student's conceptions before, during, and after instructional treatments, and (3) their ability to monitor the development of individual students' conceptions (Hewson & Thorley, 1989; Licht & Thijs, 1990; Steffe, 1983). The methods used in many studies to change students' alternative conceptions have been based principally on quantitative studies of students' generalized common conceptions (Clough & Driver, 1986; Hewson & Thorley, 1989; Cobb & Steffe, 1983). In addition, Cobb and Steffe (1983) suggested that many researchers in mathematics education have missed opportunities to interpret the dynamic changes of students' conceptions during the implementation of instructional strategies by distancing themselves from teaching and assessment in the classroom.

Purposes of the Study

The principal purpose of the original study was to develop a coherent understanding of the development of a student's conceptions during a series of teaching interventions, to explain the nature of the changes and the development of the students conceptions, to design and apply teaching interventions intended to promote the development of more scientific concepts in basic electricity, and to examine the student's reactions to specific teaching interventions. Findings were published in Katu (1992) and in Katu et al. (1993). Experiments were a dominant factor in the teaching interventions. Therefore we decided to use the data of the original study for a case study on the role of experiments in conceptual development under optimal conditions (one teacher, one student). Effects of experiments under such conditions would provide a maximum estimate of potential effects in the classroom.

Methodology

The original study used a qualitative phenomenography research methodology (Marton, 1988), more specifically the teaching experiment methodology (Cobb & Steffe, 1983). A teaching experiment consists of a series of student interviews and teaching episodes. The researcher acts as the teacher as well as an interviewer/participant-observer in the study (Steffe, 1991). As interviewer, the researcher interpreted the conceptions or conceptual framework the student used in explaining an event or phenomenon. As teacher, the researcher responded to the student's conceptions throughout the teaching sessions and designed appropriate and relevant teaching interventions. In a series of pilot studies, the researcher practiced the use of the teaching experiment methodology, tried out various interventions and alternative versions of the methodology, and tried out elements of a five phase conceptual development teaching strategy based upon the work of several researchers (Hewson & Hewson, 1983; Licht, 1987; Shipstone, 1988; Tasker & Osborne, 1985). The five phases of the teaching strategy involved practical activities as a central element and were intended to accomplish the following outcomes:

Phase 1. Help the student become aware of his or her existing ideas about the topic under consideration;

Phase 2. Enable the student to perceive a contrast between those ideas and the events that occurred in electric circuits;

Phase 3. Help the student find alternative explanations for the events that were different from the predictions;

Phase 4. Provide opportunities for the student to apply and test his or her newly developed ideas;

Phase 5. Help the student become aware of the changes that had occurred and to review and

compare the old and new ideas.

While elements of the conceptual change strategy served as a basis for teacher decisions, the five phase strategy as a whole was not employed in the main study. Too strict an application of the five phases would have conflicted with the continuity of interaction between student and researcher and with the need to base responses on student comments and conceptions.

This paper reports interactions with one student in a series of eight sessions. Each of the sessions lasted for approximately one hour. The first three sessions were focused on diagnosing the student's prior conceptions about simple electric circuits. The five sessions that followed were focused on teaching interventions designed to help the student develop more comprehensive knowledge about simple electric circuits; in addition, the student's conceptions were examined throughout all sessions.

Two physics educators with skills in classroom observation and in physics teaching observed the videotapes of the teaching experiment sessions. The principal tasks of the observers were to interpret the student's conceptions demonstrated or inferred during each session, identify important turning points in that session, provide feedback to the researcher about the researcher's behavior, and suggest possible teaching activities for the next session.

The study took place at a private high school in a small town in central Java, Indonesia. The subjects of the study were students from grade 10 and 11 who were selected through a multi-step process. Subject selection was based in part on the ability of each subject to express his or her own ideas orally. The selection was also based on recommendations from the subjects' teachers. Another criterion for the selection was the willingness of the subject to cooperate in the study and to participate in the scheduled sessions. The subjects had studied electric circuits at the beginning of grade 9 and had reviewed the topic briefly in grade 10. The study reported in this paper was conducted across 2.5 months with one student (to be called Lee in this paper) in grade 10. His tenth grade review of electricity had occurred 3 months prior to the study. The student was below average within his high school physical science stream and this probably puts him around the 80th percentile in his age cohort. The student had only very limited experience with laboratory work. At the start of the study he was not able to make correct circuits nor measure current and voltage.

Data consisted of videotapes of eight sessions, the researcher's field notes, student's worksheets, observers' notes, Indonesian transcripts, English transcripts, and background information about the student. For more details regarding the methodology and the process of guarding validity and reliability of the study we refer to Katu (1992) and to Katu et al. (1993).

Reliability and Validity: It is important to note that while the study may suggest promising hypotheses that can inform further research and implications for teaching, the results of this study can not be generalized because it was conducted with very small numbers of subjects.

Transcript analysis: Analysis for this study was done using the original transcripts in the Indonesian language. All statements relating concepts were numbered and classified in a matrix with the concepts current, voltage, resistance, power, and energy on the rows and columns. So the number of a statement linking current and voltage would be written at the intersection of the row current with the column voltage in the matrix. There was one matrix for "correct" statements and one for "alternative" statements. This enabled the researcher to easily find all statements concerning current and voltage, or resistance and power in a series circuit, etc. Statements concerning more than two major concept were recorded separately.

Remediation strategies: With students in the study the experimenter had tried out a variety of remediation strategies such as conceptual conflict, analogies, explaining electricity in microscopic terms, etc. However, in this particular study the main method used was remediation

through experiments. The researcher and the student would discuss a particular circuit, and then the student would make predictions regarding voltage and current or brightness of a bulb. Next the student would observe and measure and researcher and student would discuss the results. The electron model was used sparingly. Therefore this particular study provided the opportunity for a relatively uncontaminated study of the effects of experiments on conceptual development. The list of the experiments the student conducted are reported in Figure 1.

In the analysis of the role of experiments (the present study), the subject's predictions before each experiment were used to assess preconceptions. Then all subsequent statements relating to the concept concerned were analysed for evidence of conceptual change within a particular session and in subsequent sessions.

Figure 1

Experiments Conducted

Session #4

4.1* Effect of turning around a battery in circuit with one battery and one bulb.

4.2* Comparing the potential difference across a bulb with the potential difference across a battery in circuit with one bulb and one battery

4.3 Measuring current into (I_{in}) and out (I_{out}) of the bulb.

4.4* Brightness, current, and voltage of two bulbs in series compared to those variables in a single bulb circuit.

Session #5

5.1* Brightness of bulb placed before or after resistor.

5.2* Measurement of current and voltage in 5.1. 5.3 Feeling of heat of resistor with one battery and then with two batteries.

Session #6

6.1 Showing bubbles on the Cu plate when Cu and Zn plates are put in diluted sulphuric acid.

6.2 Measuring voltage on the plates.

6.3* Measuring current at several places of R-Bulb-R circuit.

6.4* Comparing current R-Bulb-R with R-Bulb circuit.

6.5* Comparing influence number of batteries on brightness of bulb.

6.6 Two unequal bulbs in series.

6.7 Measuring potential difference across the two unequal bulbs.

6.8 Comparing of filaments of two bulbs by observation.

6.9 One bulb replaced by another, potential differences compared again.

Session #7

7.1 Measurement of current and voltage in one resistor - two batteries circuit.

7.2 Measurement of current and voltage with two batteries, two equal resistors (<100 Ohm).

7.3 # 7.2 but with larger resistors of each 100 Ohm.

7.4 # 7.2 but with two unequal resistors.

Session #8

8.1* Two unequal bulbs in series, what is resistance and potential difference.

8.2 Two unequal bulbs parallel, predictions regarding brightness and current.

8.3 Same, measurement of currents and voltages.

Findings

Current: From the start Lee kept making statements regarding the constancy of current in a circuit. His teacher may have emphasized this very much as his teacher had conducted a little study on electricity education as part of his undergraduate degree. In session #4 he had vacillated between two views, one being that the current (and/or energy!) output of a battery would be constant regardless of the circuit, the other that the current output is determined according to the "needs" of the components. In session #5 when presented with a circuit with a resistor and bulb rather than bulbs only, Lee predicted that the current would be smaller after the resistor and that a bulb positioned on the positive side of the resistor would be less bright than a bulb positioned on the negative side of the resistor (Figure 2).

Lee (student):... mm ... because ... aa ... ... the light is brighter for this bulb L4 sir ... because here (points to figure 2) current that is supplied ... is resisted first by this resistor ... then is channeled to the bulb ... so that bulb (points to bulb L3) is dimmer than bulb L4 ... because this bulb L4 ... aa ... the current is not resisted by the resistor.

T(eacher):... so according to you how about the current in J, the current in I and the current in H (points to J, I, and H in figure 2)?

L: ... mm ... current in J is greater than [currents] in I and H ... and currents in I and H are equal. ... Because ... aa ... it is directly supplied by that battery sir ... and is resisted.

T: So I and H become smaller because their currents are resisted.

L: Yes

T: ... then ... if we compare M, L, and K?

L: M and L are equal ... but K is smaller.

T: ... is it because K has been resisted by the resistor?

L: Yes.

Insert Figure 2 here

T: ... well... aa ... Do you want to try? This is the bulb and this is the resistor. You can use one battery. (Lee constructs a circuit consisting of a bulb series with a resistor)

T: ... so the circuit you just made is similar to this (points to figure 2) ... the resistor is near the positive pole. Try to see the light first.

L: (sees the light) ... mm ... the light is dimmer sir [he compares with a reference circuit consisting of one bulb and one battery].

T: L4 is dimmer . ... Well what is your prediction if the resistor position is changed? L3 ...

L: (changes the positions of the bulb and the resistor) ... it seems the other way around sir ... it is dimmer ... compared to the light before ... equal sir!

T: mm ...

L: equal ...

T: ... equally dim?

L: Yes.

T: ... a moment ago you predicted ...

L: ... yes ... I predicted that this (points to L3) was brighter!

T: Brighter than L4?

L: Yes ... because according to me the current directly hit the bulb, and this (points to L3) was resisted first.

T: mm ... the fact that you see?

L: ... also dim!

T: You mean?

L: Equally dim!

T: ... well ... aa ... so why ... the event you see is different from what you predicted before?

L: ... mm ... maybe because ... ... aa ... the current can alternate sir.

T: What do you mean by alternate?

L: the current can ... aa ... ... mm ... ... uh ...I can't explain that yet sir.

T: ... ... aa ... how about the currents in H, I, and J. Equal or different?

L: ... ... equal sir!

T: ... then in K, L, and M?

L: ... also equal.

T: ... mm ... well try to measure the currents and also measure the voltages. Write results down here (points to figure 2)

L: Yes.

The experiment obviously contradicted Lee's predictions and from then on Lee assumed constant current in all series circuits. No current consumption statements can be found in transcripts since then. This is not to say that there were no other problems with current. Lee actually overgeneralized the result of experiment 5.1 or fitted the outcomes to another preconception, that of a battery as a constant current or energy source. For example in session #6 between experiment 6.3 and 6.4 he said: "the number of resistors put in series does not influence the current....the current that flows...but only the potential difference" and "the more resistors, the smaller the potential differences". His predictions in session #6 were consistent with this statement. Another problem was that Lee repeatedly and across all sessions stated that current has to be "shared" or "distributed" between different components such as bulbs and resistors. Yet within a given circuit he would insist on constant current. It was as if there is some kind of juxtaposition of electric current, energy, and fuel in his mind. Many students intuitively juxtapose these concepts (Niedderer & Goldberg, 1993; Berg & Grosheide, 1993).

After extensive discussion of series circuits in session #7 and at the start of #8, Lee predicted a smaller current as more bulbs or resistors are added in parallel. After more thinking he chose a fixed current (considering a battery as a constant current rather than constant voltage source is a popular alternative conception). However, when asked about what happens to the battery when more bulbs are added in parallel, he answered that the battery will be quickly exhausted and so the current would be greater with additional parallel components. He corrected himself:

L: ... mm ... the current in a parallel circuit ... the current supplied depends on ... aa ... the resistances ... great and small. If the resistance grows larger ...

the current supplied by the battery becomes smaller and vice versa. In the series circuit, as ... mm ... the resistance grows larger ... the current is the same ... constant.

T: So in the series circuit the current at all points ...

L: Constant ... stays the same.

T: In the parallel circuit?

L: Different.

T: ... If we see in the battery itself ... How about the current ... the total current supplied by the battery ... I add the number of the bulbs in a series circuit?

L: ... mm ... becomes smaller.

T: In the parallel circuit, the current supplied by the battery here if I add another bulb in parallel here ... How about the current supplied by the battery? Grows bigger or smaller?

L: Mm ... ... becomes smaller

T: ... the total current supplied?

L: mm ... ... the same!

T: The same?

L: Yes, the same.

T: So, if I add again another bulb ... so there are more bulbs I add ... how about the battery? Does it get finished faster?

L: ... It gets finished faster.

T: Why does it finish faster?

L: ... aa ... the current that is given ... ... it always constant ... but because those that use it ... ... uh I mean ... the battery gives a current ... a current that depends on the number of bulbs ... so if there are more bulbs ... and the current that is given to each of the bulbs is constant ...

T: Then?

L: ... the battery will be discharged faster.

T: So the current stays the same... If the number of bulbs increases, what happens to the battery?

L: ... aa ... the current supplied by the battery is dependent on the number of bulbs. If the number of the bulbs increases ... the current supplied by the battery also increases ... therefore ... aa ... this battery will be discharged faster compared to one or two bulbs.

T: So if there are more bulbs ... the current supplied increases.

L: Yes

T: In series circuit ... if the number of bulbs increases

L: Becomes dimmer

T: Does the current become bigger or smaller?

L: aa ... becomes smaller.

The rest of the final (session #8) interview consisted of checking and rechecking L's understanding of V, I, R, P, and E in parallel and series circuits, all with correct results and statements of Lee which sometimes involved three or more variables/concepts.

Resistance: Initially Lee did not consider a bulb as a resistor. After experiment 5.1 that changed. From then on no problems were encountered with the bulb as "a kind of" resistor. The link of resistance and current was wrong initially as explained above, however, from experiment 6.4 on, few erroneous statements are made involving resistance and current. Experiments 5.1, 5.2, 6.3, and 6.4 may have settled the link between current and resistance in series circuits, although the occasional slip (see above fragment) might indicate potential for old conceptions to resurface.

Brightness of bulb (power): Lee thought initially that brightness of the bulb was predetermined by the type of bulb (whatever was written on it). This "bulb takes the power that it

needs" model has been found frequently in other studies one of us is involved in (Berg & Grosheide, 1993). Also Niedderer and Goldberg (1993) refer to this alternative conception. Lee got over that relatively easily. That is not true with many other students. In studies of Berg & Grosheide (1993) with heterogeneous 8th and 9th graders about 20% of the students would retain this conception after 2430 lessons on electricity. In sessions #7 and #8 almost no mistakes are made anymore regarding brightness of the bulbs except for the series' circuit with unequal bulbs. Apparently the various experiments involving brightness and current had provided Lee with adequate schemes to make predictions regarding brightness.

Voltage: Before experiment 4.2, Lee predicted three times that the voltage across the bulb would be greater than the voltage of the battery that powered it. After measuring the voltage across the bulb and across the battery he reacted:

L: the same, sir!

T: mm

L: the same

T: the same?

L: yes

T ..., so we see now that the bulb and the battery are the same [he means: have the same potential difference]. Why did you think before that they would be different?

L: because...eh..on the bulb is written 2.5 Volts, sir!

Most teachers do not sufficiently emphasize that what is written on a light bulb (and other appliances) are maximum power and voltage only and that real power and voltage values depend on the circuit. Later in session #6 before experiment 6.5 there are similar problems:

T: Another question. You once said that the battery gives sufficient energy to the bulb. What did you mean by that?

L: Yes [pause] the battery uh... The bulb receives the energy as much as it is able to receive. For example, if the bulb has 1.5 volts, it is supplied with 1.5 volts.

T: If I use a 3-volt battery, do you mean that the battery only supplies 1.5 volts?

L: [Pause] The battery still supplies 3 volts, but, the bulb is only able to receive 1.5 volts.

T: So what happens to that bulb?

L: Mm The light of the bulb will be brighter.

T: If I use three batteries, the light of that bulb?

L: [Pause] The light of that bulb is still as bright, sir, as usual, or, if the battery gives 3 volts but the bulb only 1.5 volts, consequently, the bulb's brightness is a constant 1.5 volts. Even though the battery gives more, the light of the bulb is always constant.

T: So, you mean that the bulb will not be brighter.

L: No, because the bulb is only able to receive a voltage of 1.5 volts.

T: So, even though I increase the number of the batteries the brightness of the bulb stays the same.

L: Yes.

T: Do you want to try that?

L: Yes.

T: For example, you use one battery first; then use two; we'll see what happens.

(L connects the bulb to a battery and observes the brightness of the bulb.

L: The brightness is like this.

(Then he adds another battery so there are two batteries in series connected with a bulb. Lee observes again the brightness of the bulb.)

L: It is brighter.

T: What was your prediction?

L: Wrong sir. I thought the light was constant.

T: What really happens inside the circuit when you add another battery?

L: [Pause] The voltage supplied by those two batteries, those batteries supply a voltage that is greater. So, the bulb lights more brightly. But, if there is only one battery the light is dimmer.

T: What is their [points to the two batteries in the circuit on the circuit board] effect on the current that flows?

L: The current gets bigger.

T: How about the potential difference across the bulb?

L: It becomes three, greater.

L then measures the current and the voltage in the two circuits. In the circuit consisting of one bulb and one battery, he measures the current is 70 mA, and the voltage is 1.5 volts; in the circuit consisting of two batteries and one bulb he gets 100 mA for the current and 3 V for the voltage.

T: What do you find?

L: There is an increase in voltage and the current is also greater.

In predictions before experiment 4.4, Lee predicted for the voltages across two bulbs in series that $V_{L1} = V_{L2} = V_{L1+L2}$, perhaps he did not distinguish current and voltage. Yet experiment 4.2 and 4.4 seem to have done the job. Apparently Lee was able to reinterpret his school knowledge (acquired before participating in the study) and subsequently use it effectively in predicting the influence of adding components in a series circuit on the various voltages (experiments in sessions

#5-8. Almost no incorrect statements regarding the voltage-resistance relationship were recorded after session #4. On a mechanical level in simple circuits Lee was able to predict voltages correctly. For example, in session #5 he correctly predicted voltages across two and three bulbs in series (compared to one bulb) and in session #8 he correctly predicted relationships between resistance and voltage in series and parallel circuits.

Reasoning: In session #8: there are several instances of self correction. Saying something about the relationship between two variables (here current and resistance) but then thinking of a third (energy) Lee was now able to correct himself. Before there had been self-corrections also (several times in session #4) but without invoking third variables and sometimes without a reason at all, rather random self-corrections. In other words, Lee's more extensive network of relationships, or his more integrated conception framework attained self-corrective features. The fact that such corrections involved thinking simultaneously of three variables is interesting in itself. To what extent such features were retained beyond the study, we do not know.

Other: Across the eight sessions changes were observed in the subject's reasoning style and related behaviors. As the sessions progressed, the subject became much more confident, assertive, and at ease in discussing his ideas about electric circuits and his observations, interpretations, and predictions with the teacher-researcher. In the process, he appeared to become less concerned about "being wrong"; his attitudes and behaviors in the final teaching-experiment sessions were visibly more "scientific" in searching for order, organizers, and explanation than in the early sessions. These findings are especially noteworthy in the Indonesian context since the culture promotes the notion of teacher (or other higher placed adults) as respected authority figure who is not to be questioned. Students normally try to "second-guess" the teacher (and other adults) to determine "correct" responses. From the teacher's perspective there are two reasons not to like critical students: 1) culture, and 2) weak subject matter mastery by many poorly trained teachers. The latter often causes them to feel threatened by student questions, and therefore the solution is to discourage questions.

By session 8, Lee had a style and conceptual framework in place that enabled him to search for organizers and meaning and to begin to make sense of data he had generated. His explanations became less fragmented and more integrated and holistic. These changes in reasoning behaviors were noticeable and surprising after only five teaching sessions. While it is important to be cautious, the finding suggests an effect that might have a powerful long term influence on the subject's ability to develop science concepts and on his perceptions of the nature of science. Unfornately we were not able to investigate retention as the investigator and one of the observers had to go abroad for a long period right after the study.

Discussion and Implications

Experiments clearly can play a role in conceptual change. The hands-on activities with materials used in this teaching were effective in facilitating learning of correct relationships among the brightness of bulbs, the numbers of bulbs and resistors, the magnitude of current at different points in a circuit, and magnitudes of potential difference. The activities provided clear tests of the "correctness" of the subject's ideas. Frequently, they led to cognitive conflict. However, we suspect that the final understanding was still rather mechanical, allowing Lee to make correct predictions in simple circuits. Lee's conceptions of current and voltage were blurred initially and became distinct later on, however, both conceptions still overlapped with his conception of energy. Conceptual organizers such as analogies and concept maps might have achieved more in that respect and might have supported retention as well. Several authors (Dupin & Johsua, 1989; Berg & Grosheide, 1993; Niedderer & Goldberg, 1993) have reported positive experiences with the use of models in electricity education, particularly microscopic models. The practical activities alone did not enable the subject to develop a fully scientific model of a circuit system. In the hands of a sensitive teacher who promoted questioning and dialogue, they did facilitate the subject's

development of scientific reasoning skills and related behaviors.

It should be realized that the set-up in this case study was rather ideal, with one student only. The teacher/researcher could adjust all the experiments and their execution to the conceptual needs of the student. With whole classes of students, experimental results could easily be misinterpreted by individual students to fit preconceptions (Gunstone, 1990a, 1990b; Chinn & Brewer, 1993). Furthermore, electric circuits is a topic where experimental results are most clear-cut. In other branches of physics and even more so chemistry and biology, one has to make all kinds of assumptions in interpreting experiments (for example, friction in mechanics).

Experiments in this study were used in a limited way. Most experiments were of the predictobserve-explain type and intended to generate cognitive conflict. The experiments served to diagnose problems, generate conflict, and test the validity of Lee's conceptions. A powerful message packaged in the medium was that it is indeed the experiments which provide scientists with criteria to evaluate the validity of their conceptions of nature. Lee seemed to accept that and got more and more used to this role of experiments.....that after some predictions there should be an experiment. Other types (see introduction) of experiments were not used. Experiments or objects were not used to illustrate or model concepts, or to provide an analogy, or in other ways proposed in the introduction. Lee was also not involved in designing the experiments as in most situations the experiments naturally followed from a problem situation offered by the researcher. It would be interesting to try to involve the students more in designing their own circuits (Tasker & Osborne, 1985).

None of the typical reactions to anomalies as described by Chinn & Brewer were found, except for conceptual change, the least likely reaction to anomalies. A main reason for not observing these typical reactions might be the one-to-one interaction. The teacher/researcher could immediately check on interpretation of experimental observations by the student and arrange for further correction. In large classes that would not be possible (a beautiful example is described in Gunstone, 1990). Another reason might be that most reactions described by Chinne and Brewer are long term effects and this study was limited to 2.5 months. Furthermore, the cultural context in Indonesia makes students much more accepting towards experimental data obtained in the presence of the teacher. Long term retention experiments might expose limitations in the conceptual change we think we observed.

REFERENCES

Atkinson, E.P. (1990). Learning scientific knowledge in the student laboratory. In E. Hegarty-Hazel (Ed.): The Student Laboratory and the Science Curriculum. London: Routledge.

Bates, G.C. (1978). The role of the laboratory in the secondary school science programs. In M.B. Rowe (Ed): What Research Says to the Science Teacher, Volume 1. Washington DC: National Science Teachers Association.

Berg, E. van den, Giddings, G. (1992). Laboratory practical work: An alternative view of laboratory teaching. Monograph. Perth: Curtin University Science and Mathematics Education Centre.

Berg, E. van den, Darjito, A., Berg, R. van den (1992). Misconceptions on electric current and potential: Assessment and remediation. Journal of Science and Mathematics Education in S.E. Asia, 15(1), 68-80.

Berg, E. van den, Grosheide, W. (1993). Electricity at home: Remediating alternative conceptions through redefining goals and concept sequences and using auxiliary concepts and analogies in 9th grade electricity education. Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, August 1-4, 1993.

Brown, D.E., Steinberg, M.S. (1993). Qualitative models - Boon or bane in science instruction. Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, August 1-4, 1993.

Chinn, C.A., Brewer, W.F. (1993). The role of anomalous data in knowledge acquizition: A theoretical framework and implications for science instruction. Review of Educational Research, 63(1), 1-49.

Clement, J., Brown, D., Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding 'anchoring conceptions" for grounding instruction on students' intuitions. International Journal of Science Education, 11, 554-565.

Clement, J. (1994). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. Journal of Research in Science Teaching, 30(10), 1259-1257.

Closset, J. L. (1985). Using cognitive conflict to teach electricity. In R. Duit, W. Jung, &
C. V. Rhoneck (Eds.) Aspects of Understanding Electricity, 267-275, Kiel, Germany: Vertrieb Schmidt and Klaunig.

Clough E. E. & Driver, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. Science Education, 70(4), 443-496.

Cobb, P. & Steffe, L. P. (1983). The constructivist researcher as teacher and model builder. Journal of Research for Mathematics Education, 14, 34-93.

Cohen, R., Eylon, B., & Ganiel. U. (1983). Potential difference and current in simple electric circuits: A study of students' concepts. American Journal of Physics, 5(5), 407-412.

Cosgrove, M., Osborne, R., & Carr, M. (1985). Children's intuitive ideas on electric current and the modification of those ideas. In Duit et al (Eds.) Aspects of Understanding Electricity, 247-256, Kiel, Germany: Vertrieb Schmidt and Klaunig.

Dekkers, P.J.J.M., Thijs, G.D. (1993). Effectiveness of practical work in the remediation of alternative conceptions in mechanics with students in Botswana. Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, August 1-4, 1993.

Duit, R., Pfundt, H. (1991). Bibliography: Students' alternative frameworks and science education (3rd edition). Kiel: University of Kiel Institute for Science Education.

Duit, R., Goldberg, F., Niedderer, H. (1992). Research in Physics Learning: Theoretical Issues and Empirical Studies. Kiel: Institute for Science Education.

Dupin, J. J. & Joshua, S. (1987). Conceptions of French pupils concerning electric circuits: structure and evolution. Journal of Research in Science Teaching, 24(9), 791-806.

Dupin, J.J., Johsua, S. (1989). Analogies and "modeling analogies" in teaching: Some examples in basic electricity. Science Education, 73(2), 207-224.

Fredette, N. & Lochhead, J. (1980). Student conceptions of simple circuits. The Physics Teacher, 18(3), 194-198.

Garrett, R.M., Roberts, I.F. (1982). Demonstration versus small group practical work in science education. A critical review of studies since 1900. Studies in Science Education, 9, 109-146.

Gunstone, R.F. (1990). Reconstructing theory from practical experience. In B. Woolnough (Ed.): Practical Science. Open University Press.

Gunstone, R.F., Champagne, A.B. (1990). Promoting conceptual change in the laboratory. In E. Hegarty-Hazel (Ed.): The Student Laboratory and the Science Curriculum. London: Routledge.

Hewson, P. W. & Thorley, N. R. (1989). The condition of conceptual change in the classroom. International Journal of Science

Education, 11(5), 541-553.
Hodson, D. (1990). A critical look at practical work in school science. School Science Review, 70, 33-40.
Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. Studies in Science Education, 22, 85-142.
Hofstein, A., Lunetta, V.N. (1982). The role of the laboratory in science teaching: neglected aspects of research. Review of Educational Research, 52, 201-217.
Katu, N. (1992). Development of Conceptions in Basic Electricity: An Exploratory Study Using Teaching Experiment Methodology, Unpublished Ph.D. dissertation, The Pennsylvania State University: University Park, PA, USA.
Katu, N., Lunetta, V.N., Berg, E. van den (1993). Teaching experiment methodology in the study of electricity concepts. Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, New York, August 1993.
Licht, P. (1987). A strategy to deal with conceptual and reasoning problems in introductory electricity education. in J. D. Novak (Ed.) Proceedings of the Second International Seminar Misconceptions and Educational Strategies in Science and Mathematics, 275-284, Ithaca, NY: Cornell University.
Licht. P. (1990). A microscopic model for a better understanding of the concepts of voltage and current. In: Lijnse, P.L., Licht, P., Vos, W. de, Waarlo, A.J.: Relating macroscopic phenomena to microscopic particles: A central problem in secondary science education. Utrecht: CD-beta Press, 316-327.
Licht, P. & Thijs, G. D. (1990). Method to trace coherence and persistence of preconceptions. International Journal of Science Education, 12(4), 403-416.
Marton, T. (1988). Phenomenography: A research approach to investigating different understandings of reality. In Sherman and Webb (eds.), Qualitative Research in Education: Focus and Methods, 141-161, New York: The Falmer Press.
McDermott, L. C. & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigating student understanding. American Journal of Physics 60(11), November, 994 -1003.
Minstrell, J. (1982). Explaining the "at rest" condition of an object. The Physics Teacher, 20, 10-14.
Niedderer, H., Goldberg, F. (1993). Qualitative interpretation of a learning process in electric circuits. Paper presented at the

Annual Meeting of the National Association of Research in Science Teaching, Atlanta 1993.

Niedderer (1992). Personal communication. Nussbaum, J., Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principles teaching strategy. Instructional Science, 11, 183-200.

Osborne, R. J. (1983). Toward modifying children's ideas about electric current. Research in Science and Technology Education, 1(1), 73-82.

Psillos, D., Koumaras, P., & Tiberghien, P. (1988). Voltage presented as a primary concept in an introductory teaching sequence on dc circuits. International Journal of Science Education, 10(1), 29-43.

Scott, P.H., Asoko, H.M., Driver, R.H. (1992). Teaching for conceptual change: A review of strategies. In: Duit, R., Goldberg, F., Niedderer, H. Eds. (1992). Research in Physics Learning: Theoretical Issues and Empirical Studies. Kiel: Institute for Science Education.

Shipstone, D. M. (1984). A study of children's understanding of electricity in simple dc circuits. European Journal of Science Education, 6(3), 185-198.

Shipstone, D. M. (1988). Pupils' understanding of simple electrical circuits. The implications for instruction. Physics Education, 23, 92-96.

Shipstone, D. M., von Rhoeneck, C. Jung, W., Kaerrquist, C., Dupin, J. J., Joshua, S., Licht, P. (1988). A study of students~ understanding of electricity in five European countries. International Journal of Science Education, 3, 303. - 316.

Shulman, L.D., Tamir, P. (1973). Research on teaching in the natural science. In R.M.W. Travers (Ed): Second Handbook of Research on Teaching. Chicago: Rand McNally.

Steffe, L. P. (1983). The teaching experiment methodology in a constructivist research program. In Ewing et al. (Eds.) Proceedings of the fourth international congress on mathematical education. Boston: Birkhauser.

Steffe, L. P. (1991). The constructivist teaching experiment: illustrations and implications. In E. von Glasersfeld (Ed.) Radical Constructivism in Mathematics Education, 177-194, The Netherlands: Kluwer Academic Publisher.

Tasker, R. & Osborne, R. (1985). Science teaching and science learning. In R. Osborne and P. Freyberg (Eds.) Learning in Science. The implications of children's science, 112-123,

Portsmouth, NH: Heinemann.
Thijs, G.D., Berg, E. van den (1993). Cultural factors in the origin and remediation of alternative conceptions. Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, August 1-4, 1993.
White, R.T. (1979). Relevance of practical work to comprehension of physics. Physics Education, 14, 384-387.
White, R., Gunstone, R. (1992). Probing Understanding. London: The Falmer Press.